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COEFFICIENTS OF FLOW OF STANDARD NOZZLES

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COEFFICIENTS OF FLOW OF STANDARD NOZZLES.*

By H. Mueller and H. Peters.

Two new articles on the flow coefficients of nozzles and measuring orifices have recently appeared, one by Witte**, and the other by Jacob and Kretzschmer***. The flow coefficients of the V.D.I. nozzles showed considerable discrepancies. Moreover, the curves in the two series differed so greatly that we decided to do some experimenting of our own in order to determine the reason for these discrepancies. It was obvious that some of the discrepancies were due to Witte's definition of Reynolds Number, which differed from the usual definition (V.D.I., 1929, p.976), so that the discrepancies are really not so large. We first undertook experiments with air, devoted principally to the investigation of the disturbances due to the differences in the nature of the flow to the nozzle. The difficulty of measuring the air, however, caused us to experiment with water. Due to the possibility of measuring the capacity of the container, this method was much more accurate than measuring with Pitot

*"Durchflusszahlen der Normaldüse," from Zeitschrift des Vereines deutscher Ingenieure (V.D.I.), 1929, No. 27, pp.966-967.

**R. Witte, "Durchflussbeiwerte der I. G. Messmündungen für Wasser, Oel, Dampf und Gas, V.D.I., Vol. 72 (1928), p.1493.

***M. Jacob and Fr. Kretzschmer, "Die Durchflusszahlen von Normaldüsen und Normalstaurändern für Rohrdurchmesser von 100 bis 1000 mm," Forschungsarbeiten, published by the V.D.I., No. 311, Vol. 73 (1929), p.935.

tubes. Through the courtesy of Professor D. Thomas, we were allowed to perform the experiments in the hydraulic laboratory of the Munich Technical High School, which has special apparatus for weighing large quantities of water.

We tested two standard nozzles for pipes of 70 and 175 mm (2.76 and 6.89 in.) according to the 1926 rules for efficiency tests of compressors and ventilating fans. Figure 1 shows that, for constructional reasons, the places for taking the pressure behind the nozzles are not geometrically similar. Hence no exact agreement of the nozzle flow coefficients can be expected. The test pipes were smooth brass pipes arranged as shown in Figure 2. The larger nozzles of 70-175 mm (2.76-6.89 in.) diameter were affixed to pipes of about 43 D in length and the smaller nozzles of 28-70 mm (1.1-2.76 in.) diameter to pipes of about 50 D. We chose such long pipes in order to be sure of having a fairly undisturbed flow at the entrance to the nozzle.

The water was taken from an elevated tank whose over-flow arrangement maintained a uniform pressure head and hence a great uniformity of flow. The head of 16-18 m (52-59 ft.) enabled a mean velocity of 16 m/s (52 ft./sec.) in the narrowest section of the nozzle without danger of cavitation. The flow was regulated by a sluice valve s_2, the valve s_1 being left wide open during the tests. The water could be conducted by means of a swinging elbow into a tank of about 2500 liters

(660 gallons) capacity, which stood on a decimal balance, or into the waste.

The filling times were recorded by a band-chronograph with electrical contacts operated by the swinging elbow. Two manometers were used for reading the pressure, one of them containing mercury and the other air (for the smaller pressure differences). These were like the manometers described by H. Mueller.* The connection of the pressure inlet pipe with the air vents and cylinders resulted in a slight unavoidable lack of tightness. Control tests with perfect tightness or with quick-flowing cocks showed, however, that the lack of tightness caused no error in the pressure measurements. The corresponding points are therefore plotted in the diagram without special designation. The flow coefficients α were calculated by the formula

$$Q = \alpha \frac{d^2 \pi}{4} \sqrt{\frac{2g}{\gamma} (p_1 - p_2)}.$$

The results of the measurements are shown in Figure 3, α being plotted as a function of the Reynolds Number** $R = \frac{wd}{\nu}$, in which d denotes the diameter of the narrowest cross section of the nozzle, w the mean velocity in this cross section (as determined from the quantity of water), and ν the kinetic viscosity.

*H. Mueller, "Beeinflussung der Anzeige von Venturimessern durch vorgeschaltete Krummer." D. Thoma, Mitteilungen des Hydraulischen Instituts der Technischen Hochschule, Munich, No.2.
**Attention is called to the fact that all the Reynolds Numbers in Witte's paper refer to the tube diameter D.

The flow coefficients according to Figure 3 are given in the accompanying table for several Reynolds Numbers. The differences in the flow coefficients for the two nozzles may be due to lack of geometrical similarity of the places where the pressures were taken and of the shape of the nozzles. The fact that the differences can be explained by the arrangement of the pressure-measuring points alone (cf. Schutt's measurements*) admits the conclusion that the effect of the differences in the shape of the two nozzles come within the range of accuracy of the measurements.

According to a personal communication from Witte, recent J. G. experiments agree with ours within 0.1 - 0.2%. From the same communication we learned that all the Reynolds Numbers in Witte's paper refer to the diameter of the tube, contrary to the usual method. The above-mentioned considerable discrepancies largely disappear in plotting according to Reynolds Numbers with reference to the narrowest cross section of the nozzle. The flow coefficients of Witte, recalculated for the narrowest nozzle cross sections, are plotted in Figure 3, along with the mean-value curves of Jacob and Kretzschmer. We have called Professor Jacob's attention to the improbability of the S-shaped curve of the flow coefficients with respect to the measuring-orifice coefficients thereby increased. On the basis of the Witte values determined with water, we had hitherto assumed that the flow

*H. Schutt, "Versuche zur Bestimmung des Energieverlustes bei plötzlicher Rohrerweiterung." D. Thoma, Mitt. des Hydraulischen Institutes der T.H., Munich, No. 1.

coefficients of Jacob and Kretzschmer, which were based on the measurements of Jacob and Erk* for smaller Reynolds Numbers, were too small in this region. The present experiments show, however, that the lower values, within the given measuring accuracy of ±1%, agree well with ours and that, moreover, the upper values, which are based on a measuring point obtained by determining the velocity distribution, are too high. Control measurements made by us with air, whereby the quantity of air was likewise determined from the velocity distribution with similar experimental apparatus to that of Jacob and Kretzschmer, gave flow coefficients 1.5 to 2% higher than the above water measurements. This would indicate that, with the use of Pitot tubes in an irregular flow, the calculations must be made with a greater error than that assumed by Jacob and Kretzschmer (0.5%).

The present flow coefficients apply strictly only to plants, which are geometrically similar with respect to the pipes in our experimental arrangement. Here the pipe walls must also have the same degree of roughness. The effect of shorter pipes, etc., must be determined by further experiments.

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*M. Jacob and S. Erk, "Der Druckabfall in glatten Rohren und die Durchflussziffer von Normaldüsen," Forschungsarbeiten, No.267, published by the V.D.I. (Verein deutscher Ingenieure).

Flow Coefficients of the Standard Nozzles

$R = \frac{wd}{\nu}$	α		$R = \frac{wd}{\nu}$	α	
	Nozzle 28/70	Nozzle 70/175		Nozzle 28/70	Nozzle 70/175
25,000	0.947	–	200,000	0.967	0.970
35,000	0.951	0.953	300,000	0.970	0.973
50,000	0.955	0.957	450,000	0.972	0.975
70,000	0.958	0.960	600,000	–	0.977
100,000	0.962	0.964	800,000	–	0.978
150,000	0.965	0.967	1,000,000	–	9.979

Translation by Dwight M. Miner.
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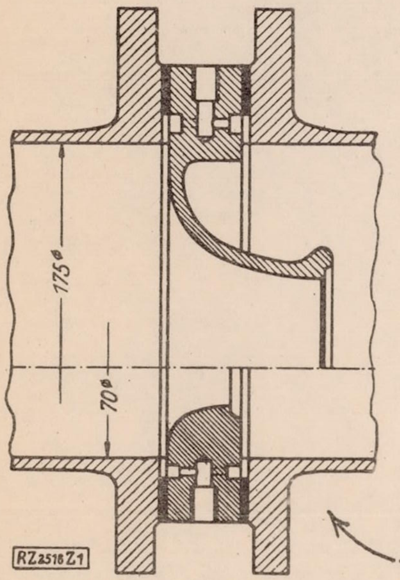

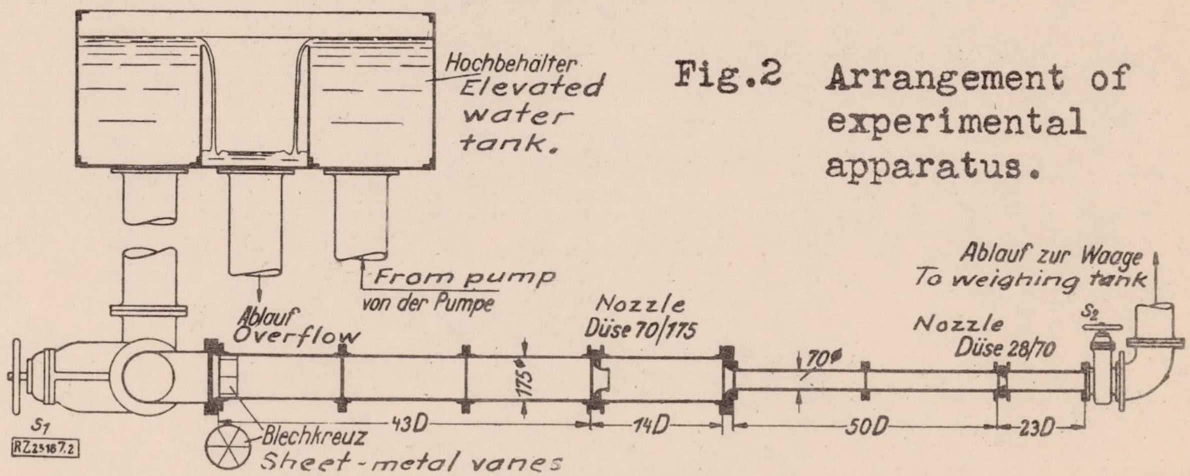

Fig.2 Arrangement of experimental apparatus.

Fig.1 Method of obtaining pressures on both sides of the nozzles.

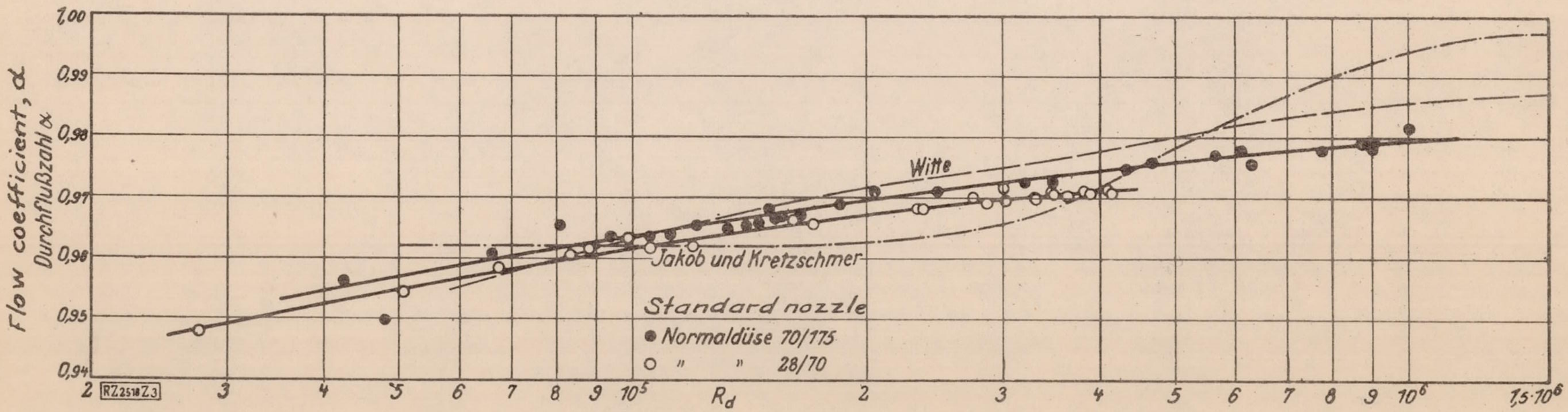

Fig.3 Flow coefficients of standard nozzles compared with experimental results of Witte and also of Jacob and Kretzschmer.